

# HIGH SPEED LASER WELDING FOR AUTOMOBILE EXHAUST COMPONENTS\*

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## Background

Arc welding has been the traditional technique for the joining of many automobile parts and components of steel. The advent of laser beam welding with its rapid speed and relatively low thermal distortion has resulted in the erosion of gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW) dominance. The faster joining speed that can be achieved with laser beam welding is particularly suited to the high-production rate requirements in the automobile industry.

Some automotive exhaust components use 409 stainless steel and are currently arc welded. Welding speeds obtained with GMAW or GTAW are usually  $<2.5$  cm/s. Weld speeds that can be achieved with high power laser beam welding can be significantly higher. Consequently, higher production rates can often be expected. This work provides preliminary data on weld speeds that can be achieved for two weld configurations subject to the constraints of material fitup requirements.

## Experiment

Test welds were performed with both cw and pulsed multi-kilowatt CO<sub>2</sub> and Nd:YAG lasers. Beam delivery with transmissive optics was used for the CO<sub>2</sub> laser (Rofin-Sinar RS6000) whereas fiberoptic beam delivery was used for the Nd:YAG lasers (Electrox 1.6kW pulsed, Lumonics 2kW Multilase). Focal lengths for the ZnSe transmissive optics used for the 28mm diameter CO<sub>2</sub> beam were 127mm and 254mm with corresponding spot sizes of 300 $\mu$ m and 600 $\mu$ m, obtained with the Prometec laser beam profiler. A 79mm back focal length focusing lens was used with the pulsed Nd:YAG laser, producing a focused spot size of 620 $\mu$ m. The focal length of the lens for the cw Nd:YAG laser was 80mm producing a spot size of 500 $\mu$ m.

Two weld joint configurations were examined. The first was an overlap joint. Two flat plates were clamped onto an x-y table with the laser beam traversing across the plates to make overlap welds. The second configuration was a coach joint as depicted in Fig. 1.

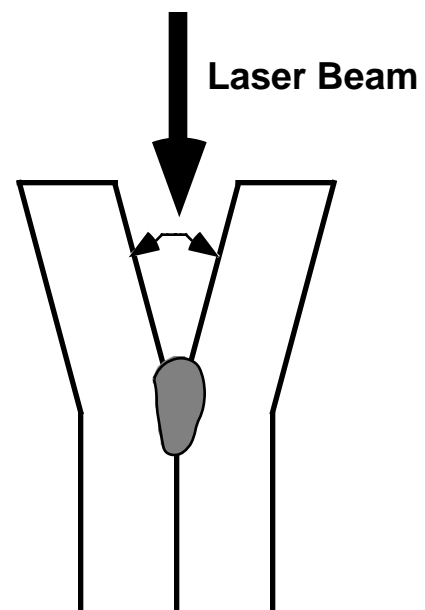


Figure 1. Schematic of coach weld

The configuration of a coach joint as used in laser beam welding is more complex than for an overlap joint and hence needs careful examination. For the case of  $\theta = 180^\circ$  the sides (6.2mm length) forming the angle are normal to the fusion zone and hence do not interact with the laser beam. The more interesting cases are when  $\theta < 180^\circ$  such that the laser beam interacts with the sides in addition to the metal at the vertex. Such a case is depicted in Fig. 2 where the focus position of the laser beam is below the vertex. The height above the vertex where the beam first impinges on the sides is given by

$$h = \frac{d \tan \frac{\alpha}{2}}{\tan \frac{\theta}{2} - m \tan \frac{\alpha}{2}}$$

where  $\alpha$  is the angle made by the converging focused beam,  $m = +1$  when the focus is above the vertex, and  $m = -1$  when the focus is below the vertex.

For the overlap weld, the parameters examined were welding speed as a function of power, weld width and spot size or beam intensity. The parameters examined for the coach weld configuration included vertical and horizontal positions of the focus, spot size and power of the laser beam, the traverse speed, angle of the bend, fitup of the two plates in terms of the airspace in between, and weld penetration.

The focus position of the beam was varied in steps of 0.5mm from 1mm above the vertex to 3mm below for a selected angle  $\theta = 20^\circ$  to determine the effect on the weld penetration and weld width. Horizontal displacements of the beam were made in steps of 0.05mm to determine the effect on joining and weld speed. The spot size of the beam was varied by changing the focal length from 127mm to 254mm.

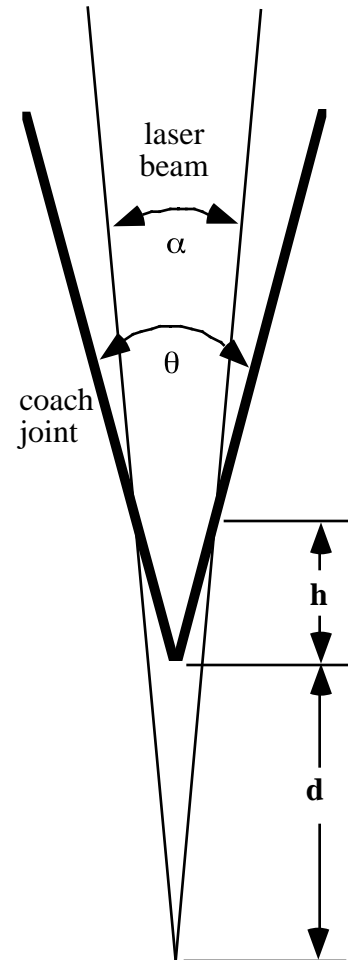


Figure 2. Outline of laser beam in relation to vertex of coach joint.

The laser power used was from 500W to 6kW for the CO<sub>2</sub> laser and 500W to 2kW for the Nd:YAG. Weld speeds were obtained for lap welds at the range of power levels given for both the CO<sub>2</sub> and Nd:YAG lasers. Later welds for the coach joint were obtained mostly at 2kW (with the CO<sub>2</sub> laser) with a few welds using the 254mm focal length lens at higher powers. The transverse speed of the x-y table was varied for a prescribed laser power until a full penetration lap weld was achieved. In the case of the coach joint, traverse speeds were varied in steps of 1.05 cm/s (25 ipm) to achieve a continuous weld at the fastest speed. The angle  $\theta$  of the coach joint was varied from  $10^\circ$  to  $30^\circ$  in steps of  $5^\circ$ . Poor fitup of the coach joint was simulated by placing shim stock in between the plates. The fitup ranged between 50  $\mu$ m and 250  $\mu$ m.

## Results and Discussions

### Overlap Joint

For overlap welds, weld speeds were obtained as a function of beam power for the CO<sub>2</sub> and Nd:YAG lasers. The materials tested were 409 stainless steel flat stock with a nominal thickness of 1.5mm (3mm lap weld) and aluminum-bearing stainless steel (12sr) flat stock of 0.81mm thickness. Details of this lap weld study can be found elsewhere<sup>1</sup>. For the laser and spot sizes used, the weld widths at the interface of the plates did not vary significantly (1.0mm - 1.2mm) even though the weld profiles varied from partially conductive type to keyhole type. Data on the variation of weld speed with power of the cw CO<sub>2</sub> and Nd:YAG lasers are shown in Fig. 3. An interesting deduction from this study is that for a required depth of penetration, weld speeds will be very similar for all the lasers used if the beam intensity is adequate

(optimal). It should be noted that the spot sizes of the different laser beams are not identical. The traverse speeds obtained with the cw Nd:YAG laser are consistent with those obtained with the cw CO<sub>2</sub> laser using the 254mm lens. This consistency is because of the similar beam intensities whereas in the case of the 127mm lens substantially higher intensities produced higher weld speeds. In addition, weld porosity can be controlled by increasing beam intensity or decreasing spot size.

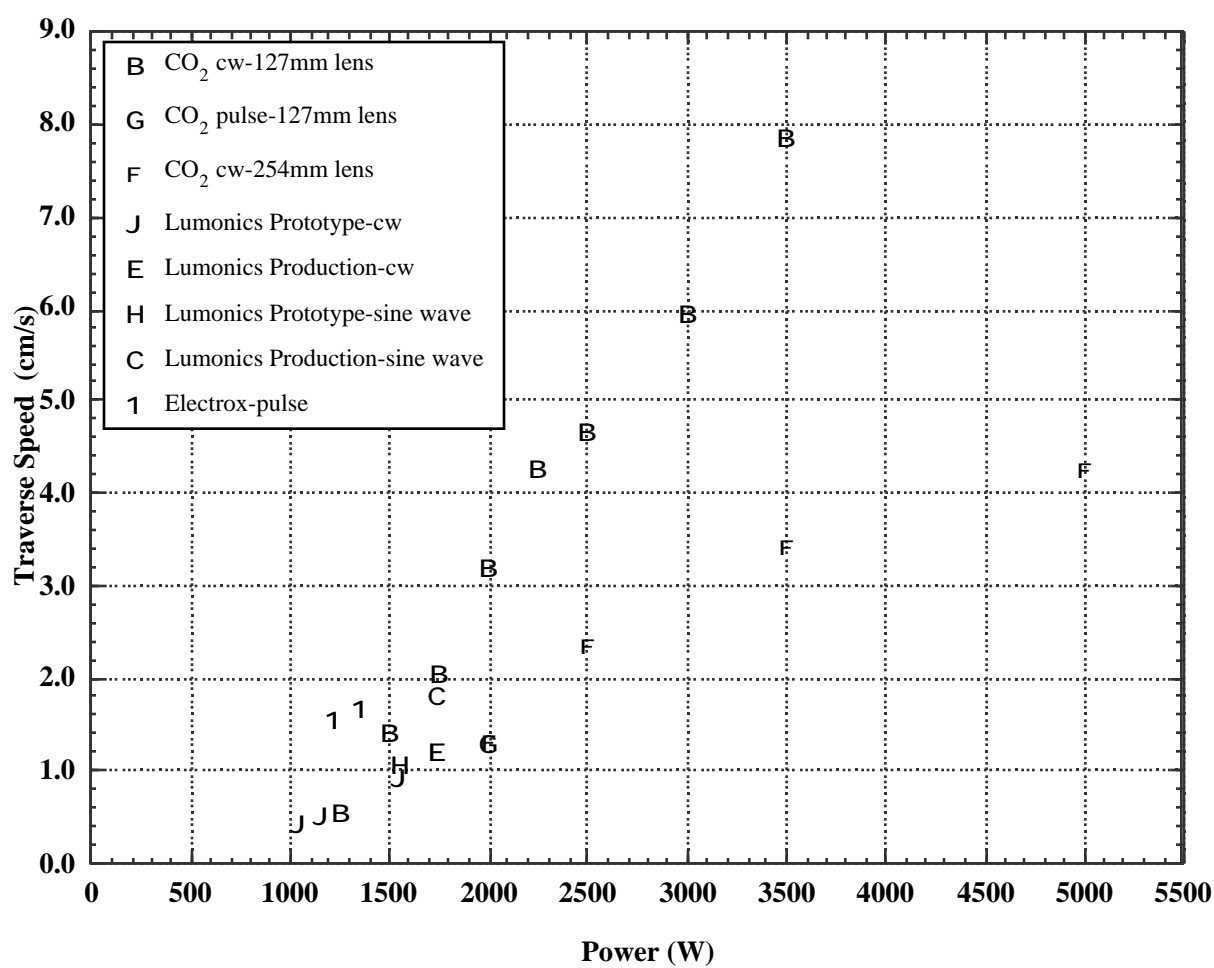


Figure 3. Weld speeds obtained for full penetration lap welds on 409 stainless steel using CO<sub>2</sub> and Nd:YAG lasers.

### Coach Joint

Considering the range in output beam power available and the need for high speeds, the CO<sub>2</sub> laser was selected for more detailed studies with different weld configurations. Since the relevant parameter is the width of the joint, a more efficient weld configuration is the coach joint where the laser beam is directed at the interface between the two plates (Fig. 1), whereas, for the lap weld, energy has to be expended to penetrate through the top plate. An initial thought with the coach weld is that the angle formed by the bend on the edge of the two plates may help to focus the laser beam energy into the fusion zone.

Weld tests were initially performed using the 254mm focal length lens with a spot size of 300µm. This lens produced a converging beam with  $\theta = 12.6^\circ$ . An angle  $\theta$  of  $20^\circ$  was selected for initial tests on the effect of traverse speed on weld penetration and width. A focus position of 1.5mm above the vertex was selected so that the beam would not impinge on the sides. Examination of the weld profiles confirmed the expectation that the weld formed around the vertex and a decreasing weld penetration with traverse speed. All welds were free of cracks with no porosity. The angled sides aided in forming part of the weld above the vertex. The width of the weld decreased with traverse speed as evident in the two weld profiles in Figs. 4a and 4b for the slowest and fastest traverse speed. The fastest speed used is the maximum speed

that will produce a continuous weld. Note that the fastest speed of 10.6 cm/s at 2kW is substantially higher than the fastest speed (4.6 cm/s) obtained with overlap welding, at the same beam power level. In addition, the weld penetration of 1.7mm obtained with the coach joint is better than the 1.1mm weld width at the interface for the overlap joint. The variations of the weld penetration and width with traverse speed are plotted in Fig. 5.

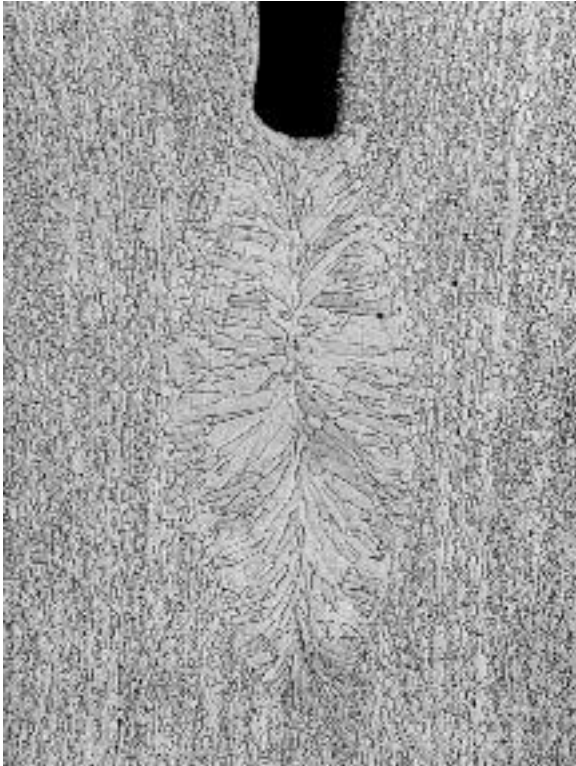


Fig. 4a. Weld profile of coach joint. Traverse speed used was 3.2 cm/s.  $\theta = 20^\circ$ .  $d=2\text{mm}$ . The width of this picture is 3.05mm.

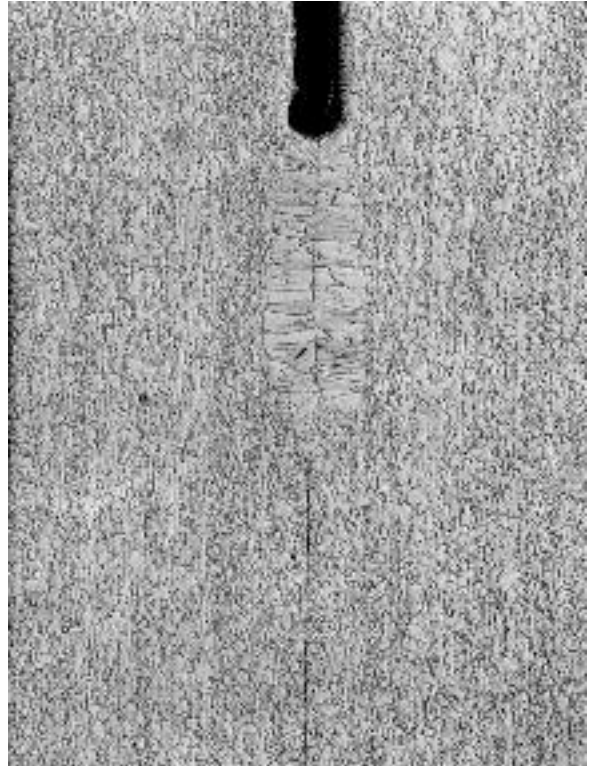


Fig. 4b. Weld profile of coach joint. Traverse speed used was 10.6 cm/s. The width of the picture is 3.05mm.  $\theta = 20^\circ$ .  $d = 2\text{mm}$ .

The effects of the focus position on weld penetration and position were examined at the fastest traverse speed used in Fig. 5 i.e., at 10.6 cm/s (250 ipm) and at the same value of  $\theta = 20^\circ$ . The focus position was varied in steps of 0.5mm from 1mm above the vertex to 3mm below. The use of focus positions at and above the vertex resulted in welds forming around the vertex with no porosity. Focus positions below the vertex resulted in welds forming above the vertex with an air gap below the weld. The weld penetrations were shallow ( $\sim 0.5\text{mm}$ ). The weld profile for  $d = 2\text{mm}$  below the vertex is shown in Fig. 6. The dependence of  $h$  on focus position is plotted in Fig. 7. The position of the top of the weld increases in height above the vertex as the focus position below the vertex increases. This variation is not as simplistic as the predicted variation of  $h$  with  $d$ , but is generally physically consistent with the geometry of the problem.

An interesting observation is that the angle  $\theta$  after welding becomes smaller by  $4^\circ$  to  $8^\circ$  independent of the focus position used. This change in angle after heating by the laser beam appears to be related to weld shrinkage and release of residual stresses.

Further tests were carried out using a focus position of 1.5mm below the vertex to explore the impact of fitup, alignment and value of  $\theta$  on traverse speed and penetration. Misalignment in terms of a horizontal displacement of the beam normal to the direction of the weld of up to 0.3mm allowed the formation of a continuous weld at a traverse speed of 10.6 cm/s. Weld penetrations were similar to the case of no displacement. Slower traverse speeds permitted a higher displacement (misalignment) with an increase to 0.4mm at a traverse speed of 6.3 cm/s (150 ipm). The slower traverse speeds tended to produce welds of deeper penetration, but usually with an air gap above the vertex.

Substantially lower traverse speeds were necessary to form a continuous weld where shim stock was used to create a gap between the plates. Traverse speeds decreased from 8.5 cm/s (200 cpm) at a gap of 50  $\mu\text{m}$  to 2.1 cm/s (50 ipm) for a gap of 250  $\mu\text{m}$ . Changing to the 254mm focus lens with the larger spot size allowed higher traverse speeds.

The data obtained indicate that the presence of a lip (sides forming the angle ) affects the welding of the coach joint. For values of small enough such that the beam impinges on the sides above the vertex, weld penetration is detrimentally impacted. However, for values such that the sides do not interfere with the beam and focus positions slightly above the vertex, the lip appears to aid in forming the weld that extends from below to above the vertex. For these beneficial conditions, the coach joint configuration is substantially more efficient than the lap joint for a required weld strength per unit length. Work is in progress to determine the envelope of the parametric effects on the welding of the coach joint.

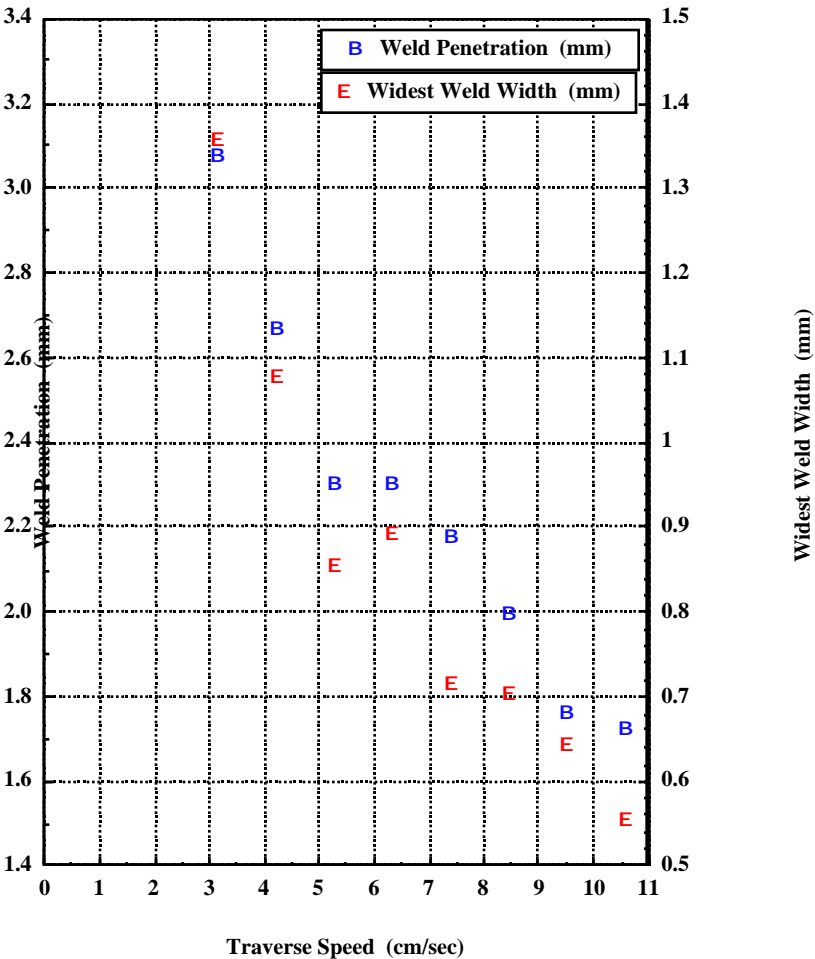
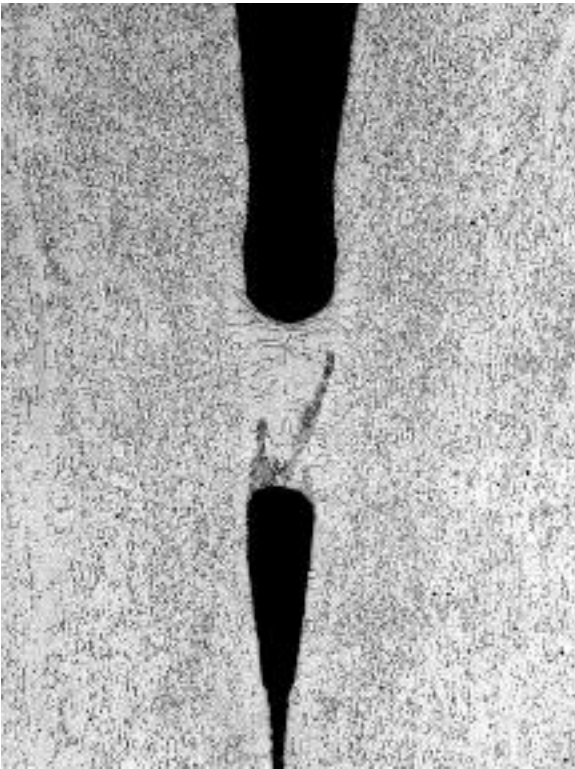


Figure 5. Weld penetration and width as a function of traverse speed for the coach joint. The focus position was at 1.5mm above the vertex and the beam power was 2kW.

Fig. 6. Weld profile of coach joint. Traverse speed used was 10.6 cm/s.  $\theta = 20^\circ$  d = 2mm. The width of this picture is 1.90mm.



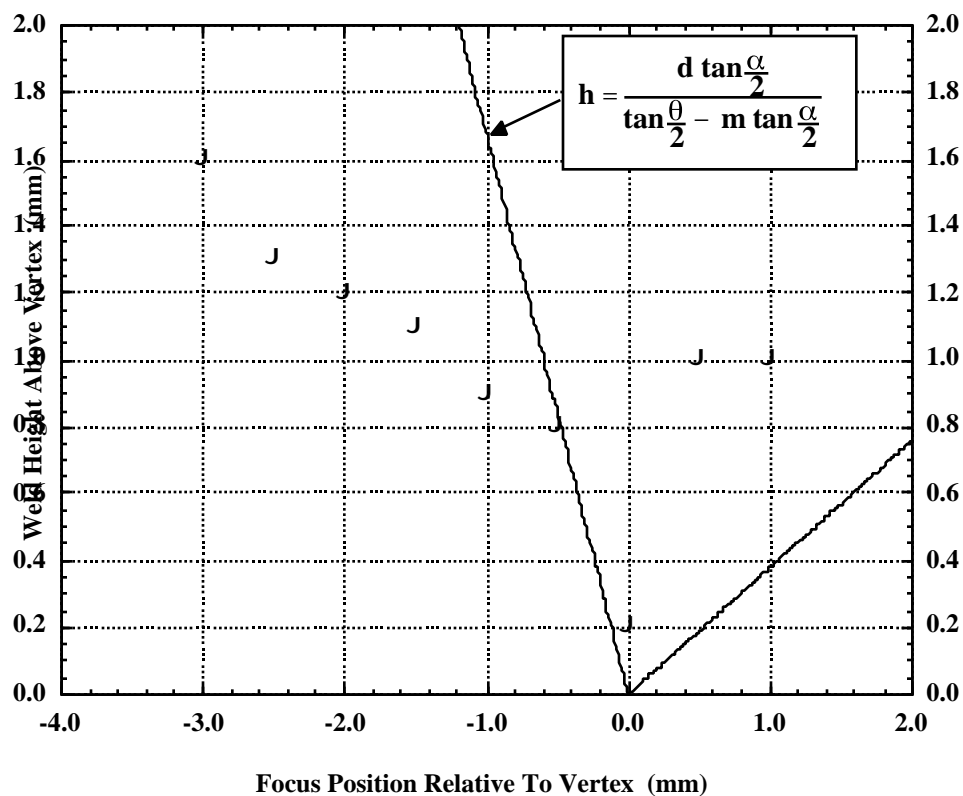


Figure 7. Height of the top of the weld produced as a function of the focus position used for the coach joint. The beam power used was 2kW and  $\theta = 20^\circ$ .

### Acknowledgment

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### References

1. Leong, K. H., L. A. Carol, H. N. Bransch (1994) Welding with High Power CO<sub>2</sub> and Nd:YAG Lasers, Industrial Laser Review, June.